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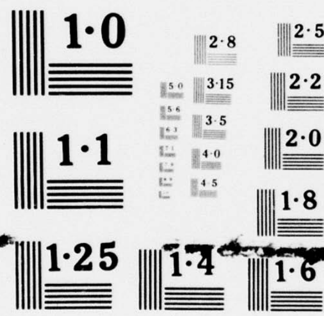
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FINAL REPORT

RESEARCH ON MANNED SYSTEM DESIGN USING OPERATOR MEASURES AND CRITERIA (OMAC) DATA

E. M. Connelly

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In manned systems, performance can change significantly with changes in display design. With today's computer and display technology, it is possible to provide virtually any display function desired including automating many of the information processing tasks previously performed by the human operator. However, the relationship between display design and total system (people and machine) performance must be known in order to systematically select display features. The object of this research program was to investigate

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system performance models for ship control as an aid to ship display and control design.

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OMAC models representing performance obtained with each display design reveal that performance differences are explained by differences in a constraint self-imposed by the operator to select only a portion of the display information in order to control the ship. Constraint differences are equivalent to differences in the amount of information processed by the OOD with each display design. Further, the hypothesis that OOD participants using different displays attempt to perform according to invariant performance criteria was confirmed for superior performances. The hypothesis was not confirmed for less than superior performances.

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ABSTRACT

In manned systems, performance can change significantly with changes in display design. With today's computer and display technology, it is possible to provide virtually any display function desired including automating many of the information processing tasks previously performed by the human operator. However, the relationship between display design and total system (people and machine) performance must be known in order to systematically select display features. The object of this research program was to investigate system performance models for ship control as an aid to ship display and control design.

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1.0 INTRODUCTION

This report is the final report on contract number N00014-75-C-0810 between Omnemii, Inc. and Engineering Psychology Programs, Office of Naval Research. The contract was initiated on 1 April 1975 and completed on 30 May 1977.

The objectives of the research were to:

1. Develop a ship display/control design tool which would permit a designer to select alternative display features based on their effect on system performance.
2. Develop a method of representing operator control actions and resulting ship responses by the criteria optimized by those ship responses. This type of model is called "operator measures and criteria" (OMAC) model.
3. Devise a method of using the OMAC model to predict operator control actions and resultant ship responses in a variety of problem situations.
4. Develop a sensitive measure of contact (ship) avoidance performance.

This research program used data which had been previously collected during a series of experiments in which participants acting as Officer of the Deck (OOD) controlled a simulated ship in a simulated environment. The task was to direct a ship transit from the initial point to the terminal point within a pre-specified time interval while avoiding simulated contacts along the way. The experiment, using equipment known as the Surface Ship Bridge Console System (Beary; Gawitt), was run by personnel of NSRDC, Annapolis, Maryland, for purposes other than this research program. The data from that experiment were used in the research reported here.

Reports describing the research are listed in the section on reports distributed. Results of the research are summarized in the following paragraphs.

2.0 MAJOR RESULTS OF THE RESEARCH

2.1 Contact Avoidance Performance Measurement

Performance of manned systems is typically measured with summary measures, i.e., measures that summarize performance over the total simulated or actual mission. Examples of such measure components applied to ship control are:

1. Transit time;
2. Average deviation from a reference course;
3. Number of collisions or near collisions;
4. Fuel efficiency; and
5. Number of course and speed changes.

These components are usually weighted and summed to form the composit summary measure. However, such summary measures did not reveal the performance differences that existed with different displays tested in the ship control experiments referred to previously. Fortunately, a sensitive contact avoidance measure was developed as part of the research on this program to identify OMAC's that represent operator performances. With this measure, the performance differences with different displays were revealed.

Of importance here is not only discovery of improved performance with the advanced displays, but also the development of the sensitive contact avoidance performance measure. The success of

the measure supports the measurement principle: measures that detect responses leading to a critical condition (a ship collision) are more sensitive than measures that detect only the critical condition.

2.2 OMAC Modeling Concept

Performance prediction models have long been sought to aid in system design and to better understand how display designs affect performance. Present modeling methods (Connelly; Kleinman; McRuer; Preyss; Sheridan) which typically represent the human operator's moment-to-moment control response, have not provided the necessary predictive models. There are several difficult problems to overcome. One problem is that performance models should be applicable to operational or near operational settings and not limited to laboratory problems. Operational settings frequently require non-linear operator response functions - thus prohibiting the use of linear models. Another problem is that prediction of human response or human controlled system response on a moment-by-moment basis does not permit prediction of present response based on present conditions <u>and</u> the anticipated or planned activity by the operator. The modeling method used in the analysis reported here employs a construct based on optimal control theory to provide performance prediction.

Optimal control theory provides a means for determining the system response which, within the constraints imposed, is best according to the specified criteria. Given criteria and constraints, optimal control theory permits evaluation of all possible responses that satisfy the constraints, and in doing so identified the response that is best according to the criteria. Its property of interest here is that it relates system responses to criteria and vice versa. With this capability, it is possible to model a response by identifying the criteria optimized. This modeling process is the inverse of the process used by the designer of an automatic control system wherein criteria are selected first followed by determination of system responses that optimize those criteria. The inverse process used in this study starts with observed responses and seeks to identify the criteria optimized by these responses.

For manned systems, the OMAC criteria found to be optimized by observed responses should be distinguished from task criteria typically established by the system designer to specify desired system performance. While the OMAC criteria and the task criteria may be identical or similar, they are not necessarily the same; differences would reflect a lack of mutual understanding of task performance requirements. Also regarding manned systems, constraints can be imposed by the equipment (e.g., limited rudder deflection) or imposed by the operator (e.g., use of only a portion of the display information).

The control task considered here is a ship control problem where the OOD is to direct the ship from a starting location to an objective location and arrive at the objective in 90 minutes. The ship is to be controlled so as to avoid all contacts (other ships) by at least 3.70 kilometers (2 nautical miles). A task performance measure for this problem was developed using measures of transit time and contact avoidance. This task measure penalizes for excessive transit time and for passing contacts closer than 3.70 kilometers (2 nautical miles). The ship control involves equipment constraints such as an upper limit to speed and a lower limit to turning radius. Using the OMAC criteria analysis described, ship transiting responses which included contact avoidance maneuvering were modeled by the criteria optimized.

2.3 OMAC Representation of Operator Performances

OMAC's were identified for each operator performance. The ability of the OMAC's to represent individual performances was shown to be a function of the level of operator performance, i.e., superior performers were represented more accurately than were less skillful performers. In spite of difference in accuracy of representation, the representation is sufficiently accurate to permit prediction of operator performance, i.e., prediction of operator performance using OMAC's in a statistically significant manner.

A major result of the research was that for the ship control problem considered, OMAC must include both the criteria optimized and a purview constraint. Without both criteria and constraint, accurate modeling was not possible. The purview constraint found useful in the OMAC model represents a radius from own ship within which all contacts are considered. Contacts outside that radius are not considered for ship control. Other constraints such as considering a limited number of contacts may be useful but some type of purview function is necessary.

2.4 OMAC Representation of Performance With OLD and PACS Displays

OMAC's representing operator performance with two different display types (OLD and PACS[1]) for two population groups (all participants and superior participants) were identified. From the results, several conclusions were possible.

1. A greater proportion of the performers were rated superior with the PACS display than with the OLD display. This suggests that with the PACS display there would be more superior performers in the general OOD population.

2. Superior performers with PACS and OLD displays are represented by the same OMAC criteria (the relative weighting

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[1] OLD display is a conventional radar PPI display, PACS (Possible Area of Collision) is an advanced display that provides among other features the locus of collisions with all contacts for all possible own ship courses.

between contact avoidance and transit time). The average performance level with the two displays is different but the criteria optimized are the same. This suggests that consistent "target" criteria (the criteria sought by the operator) were the goal of superior performers with both displays; but, the operators were better able to reach that performance goal with the PACS display. This result suggests that the "target" criteria might be used in training where operators could be rated not only on performance but also on the criteria they apparently optimize.

3. Performance differences with different display types obtained from the superior performances are explained by a difference in purview (the range from own ship within which the operator processes contact data). The logic is: OMAC predicts operator performance; OMAC has two parts: criteria and purview; but, the criteria are constant while purview changes with changes in display. Indeed, the OMAC performance data show clearly the effect of purview on performance.

4. The purview rating for the OLD display was found to be 17.77 kilometers (9.6 nautical miles) while the PACS display was found to be 22.22 kilometers (12 nautical miles). Purview rating may be a function of contact density and thus the ratings given should not be considered absolute; but, only apply for the experimental control task.

5. The average number of contacts within purview in the experimental problem was a linear function of purview area. Thus, OOD shiphandling performance may be a function of the number of contacts that the OOD can process with a given display design. If a display feature automates one or more information processing tasks, the OOD may be able to process more contacts, thus expanding his purview. According to the results discussed above (3), this would result in improved performance. This logic suggests that an analysis of the information processing required of the OOD per contact may permit direct prediction of OOD ship handling performance.

2.5 Representation of Human Performance by the OMAC Optimized

Based on the overall results obtained with the OMAC, it is concluded that the criteria modeling approach offers a practical way to model human performance in an operational or near operational problem setting. The generality of the method to other manned system problems should be investigated.

With this modeling method, the operator's output at each instant of time is represented by taking into account both the instantaneous problem state and planned operator outputs as a result of projections of controlled device responses. Projections of controlled device responses are the expected future responses of the device(s) or expected behavior of disturbing factors such as the contacts of the ship control problem.

Representative OMAC's reveal the target criteria of the human controller and permit evaluation of the ability to perform according to those criteria. OMAC's also reveal the constraints that may be self-imposed or are inherent, but which limit the operator's performance level.

OMAC's can be developed for individuals working with complex and non-linear tasks. The complexity of the task or the device being controlled does not limit the identification of the apparent OMAC.

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